

5           **INTEGRATED MULTIMODE RADIO AND COMPONENTS THEREOF**

**TECHNICAL FIELD OF THE INVENTION**

10           This invention relates generally to wireless communications and more particularly to an integrated radio receiver and/or integrated radio transmitter.

15           **BACKGROUND OF THE INVENTION**

          The use of wireless communications for in-home, in-building networks, and/or direct communication is increasing in popularity and spawning relatively new standards including, but not limited to, Bluetooth, IEEE 802.11a, IEEE 802.11b, et cetera. As is known for wireless communications, data is modulated onto at least one radio frequency (RF) carrier frequency and transmitted as an RF modulated signal by a radio transmitter. A radio receiver receives the RF modulated signal and demodulates it to recapture the data.

          As is further known, there are a variety of modulation/demodulation protocols that may be used for wireless communications. Such modulation/demodulation protocols include amplitude modulation (AM), frequency modulation (FM), amplitude shift-keying (ASK), frequency shift-keying (FSK), phase shift-keying (PSK), orthogonal frequency division multiplexing (OFDM), and/or variations thereof.

Regardless of the particular modulation/demodulation protocol, a radio receiver generally includes an antenna section, a filtering section, a low noise amplifier, an intermediate frequency (IF) stage and a demodulator. In operation, the antenna section receives RF modulated signals and provides them to the filtering section, which passes RF signals of interest to the low noise amplifier. The low noise amplifier amplifies the received RF signals and provides the amplified RF signals of interest to the IF stage. The IF stage includes one or more local oscillators, one or more mixers, and one or more adders to step-down the frequency of the RF signals to an intermediate frequency or base band frequency. The IF stage provides the IF or base-band signals to the demodulator, which, based on the particular modulation/demodulation protocol, recaptures the data.

While the basic elements of a radio receiver operating in accordance with one wireless standard perform generally the same functions as the basic elements of a radio receiver operating in accordance with another wireless standard, the specific functionality and construct of such elements may vastly differ. For example, the elements of a radio receiver designed in accordance with the Bluetooth specification have a substantially different specific functionality, and thus construct, than corresponding elements of a radio receiver designed in accordance with the IEEE 802.11b standard.

The specific functionality differences between the basic elements of a Bluetooth radio receiver and those of

an IEEE 802.11b radio receiver result from the differences between the physical layer requirements of the two specifications. For instance, Bluetooth provides up to a 1 megabit-per-second data rate by employing a frequency-hopping scheme (i.e., 97 hops at 1 megahertz spacing) in the 2.4 GHz frequency band, such that the frequencies of interest are 2.402 GHz to 2.480 GHz. Bluetooth also specifies an FSK modulation/demodulation scheme and provides for 3 power classes (e.g., 1 mW, 2.5 mW and 100 mW). As such, a Bluetooth radio receiver includes a low noise amplifier, a 1<sup>st</sup> IF stage operating with a 2 MHz intermediate frequency, band-pass filters, a 2<sup>nd</sup> IF stage operating with a base-band frequency, and an FSK demodulator.

The IEEE 802.11b standard provides a variable data rate of 1, 2, 5.5, or 11 Mbps (megabits-per-second) by employing a direct sequence spread spectrum (DSSS) transmission scheme in the 2.4 GHz frequency band, such that the frequencies of interest are 2.400 GHz to 2.483 GHz. To achieve the 11 Mbps data rate, data is encoded using an 8-bit complimentary code keying (CCK) algorithm and modulated using a differential quadrature phase shift-keying (DQPSK) scheme. For a 5.5 megabit-per-second operation, the CCK encoded data is modulated using a differential binary phase shift-keying (DBPSK) modulation scheme. As such, an IEEE 802.11b compliant radio receiver includes a low noise amplifier, an IF stage having a base-band intermediate frequency, low pass filters, gain stages, and a DQPSK and/or DBPSK demodulator.

Since both IEEE 802.11b and Bluetooth specifications were created for localized (e.g., in-building, in-home, in parking lots, in stadiums, in hospitals, et cetera) wireless communications, it is conceivable that some wireless applications would be better served by Bluetooth while other wireless applications would be better served by 802.11b. In such an instance, it would be desirable for a wireless communication device to be able to operate in accordance with both the Bluetooth standard and the 802.11b standard. But, to do so, the device requires a separate Bluetooth radio (i.e., Bluetooth radio transmitter and Bluetooth radio receiver) and a separate 802.11b radio (i.e., 802.11b radio transmitter and 802.11b radio receiver). Such additional circuitry, while providing additional functionality, adds to the cost and complexity of such wireless devices.

Therefore, a need exists for an integrated radio receiver and/or integrated radio transmitter that support multiple wireless communication standards including, but not limited to Bluetooth and IEEE 802.11b.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 illustrates a schematic block diagram of an integrated multimode radio in accordance with the present invention;

Figure 2 illustrates a schematic block diagram of an alternate integrated multimode radio in accordance with the present invention;

Figure 3 illustrates another integrated multimode radio in accordance with the present invention;

Figure 4 illustrates a schematic block diagram of a multimode receiver in accordance with the present invention;

Figure 5 illustrates a schematic block diagram of a multimode transmitter in accordance with the present invention;

Figure 6 illustrates a schematic block diagram of an alternate multimode receiver in accordance with the present invention;

Figure 7 illustrates a schematic block diagram of an alternate multimode transmitter in accordance with the present invention; and

Figure 8 illustrates a schematic block diagram of yet another integrated multimode radio in accordance with the present invention.

#### **DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT**

Figure 1 illustrates a schematic block diagram of an integrated multimode radio 10 that includes a multimode receiver 12 and a multimode transmitter 14. The multimode receiver 12 includes a shared receiver front-end 16, a receiver multiplexor 18, and a plurality of receiver IF stages 20 and 22. The multimode transmitter 14 includes a

shared transmitter front-end 42, a transmitter multiplexor 40, and a plurality of transmitter IF stages 36 and 38.

The shared receiver front-end 16 receives a radio

5 frequency (RF) signal 24 and a selection signal 34. The selection signal 34 indicates the particular operational mode used to generate the RF signal 24. The RF signal 24 is a modulated signal in accordance with a particular operation mode, i.e., wireless communication standard.

10 Such wireless communication standards include, but are not limited to, Bluetooth, IEEE 802.11a, IEEE 802.11b, analog mobile phone service (AMPS), digital AMPS (D-AMPS), global system for mobile (GSM), code division multiple access (CDMA), wireless application protocol (WAP), local  
15 multipoint distribution services (LMDS), and multi channel multipoint distribution system (MMDS).

The shared receiver front-end 16, based on the selection signal 34, generates an intermediate frequency  
20 (IF) signal 26 from the RF signal 24. For example, if the RF signal 24 is modulated in accordance with the Bluetooth specification, the selection signal 34 is indicative of the Bluetooth specification. Accordingly, the shared receiver front-end 16 configures itself to produce an IF signal 26  
25 having an intermediate frequency of 2 megahertz.

Alternatively, if the RF signal 24 is modulated in accordance with the IEEE 802.11b standard, the selection signal 34 is indicative of IEEE 802.11b. Accordingly, the shared receiver front-end 16 configures itself to produce  
30 an IF signal 26 that has an intermediate frequency at base-band. The construct and internal operations of the shared

receiver front-end 16 will be described in greater detail with reference to Figures 4 and 8.

The receiver multiplexor 18 receives the IF signal 26 and selection signal 34. Based on the particular operation of mode indicated by the selection signal 34, the receiver multiplexor 18 provides the IF signal 26 to one of the plurality of receiver IF stages 20 and 22. As one of average skill in the art will appreciate, the multimode receiver 12 may include more receiver IF stages than the two depicted. However, if the integrated multimode radio 10 is designed to provide both Bluetooth and 802.11b applications, the multimode receiver 12 would include two receiver IF stages. One receiver IF stage would be configured for Bluetooth operations while the other is configured for 802.11b operations.

When the 1<sup>st</sup> receiver IF stage 20 receives the IF signal 26 it produces a 1<sup>st</sup> receiver IF signal 28. If the 2<sup>nd</sup> IF stage receives the IF signal 26 it produces a 2<sup>nd</sup> received IF signal 30. The construct and functionality of the receiver IF stages 20 and 22 will be described in greater detail with reference to Figures 3, 4, and 8.

As such, the multimode receiver 12 may be designed to meet the performance requirements of multiple wireless standards. For example, if the multimode receiver 12 is designed to meet the performance requirements of both Bluetooth and 802.11b specifications, the shared components of receiver 12 are designed to meet the more stringent requirements of 802.11b. By designing to the more

stringent requirements, the less stringent requirements of Bluetooth will inherently be met.

The multimode transmitter 14 receives an input signal 44 via one of the plurality of transmitter IF stages 36 or 38. The number of transmitter IF stages included within transmitter 14 will depend on the number of different types of wireless specifications supported by the integrated multimode radio 10. For example, if the integrated multimode radio 10 supports Bluetooth and 802.11b, the transmitter 14 will include one transmitter IF stage for the Bluetooth mode (e.g., stage 36) and one for the 802.11b mode (e.g., IF stage 38). As one of average skill in the art will appreciate, when the selection signal 34 is indicative of one mode of operation, the IF stage 36 or 38 that corresponds to the other mode of operation may be disabled. This is equally applicable to the receiver IF stages 20 and 22. For example, if the selection signal 34 is indicative of Bluetooth operation, the transmitter IF stage and the receiver IF stage corresponding to the 802.11b operation would be disabled.

The enabled transmitter IF stage 36 or 38 generates a transmitter IF signal 46 or 48 dependent on the particular mode of operation. The operation of the 1<sup>st</sup> transmitter IF stage 36 and 2<sup>nd</sup> transmitter IF stage 38 will be described in greater detail with reference to Figures 3, 5, and 8.

The transmitter multiplexor 40 passes either the 1<sup>st</sup> transmit IF signal 46 or the 2<sup>nd</sup> transmit IF signal 48 to the transmitter front-end 42 as the selected IF signal 50 based on the selection signal 34. The transmitter front-



end 42 up-converts the frequency of the selected IF signal 50 and amplifies it to produce the outbound RF signal 52. Note that the outbound RF signal 52 will be modulated in accordance with the particular operational mode of the particular operation of mode selected. For example, if the operational mode is Bluetooth, the outbound RF signal 52 will be in accordance with the Bluetooth standard. Alternatively, if the mode of operation is 802.11b, the outbound RF signal 52 will be in accordance with the 802.11b standard.

Figure 2 illustrates a schematic block diagram of an alternate integrated multimode radio 60 that includes a multimode receiver 62 and a multimode transmitter 64. The multimode receiver 62 includes a shared receiver front-end 66, a 1<sup>st</sup> receiver multiplexor 68, a receiver low pass filter 70, a receiver band-pass filter 72, a 2<sup>nd</sup> receiver multiplexor 74, and a receiver amplifier module 76. The multimode transmitter 64 includes a transmitter amplifying module 88, a 1<sup>st</sup> transmitter multiplexor 90, a first transmitter low pass filter 92, a second transmitter low pass filter 94, a 2<sup>nd</sup> transmitter multiplexor 96, and a shared transmitter front-end 98.

The shared receiver front-end 66 is operably coupled to receive the RF signal 24. As previously mentioned, the RF signal 24 may be modulated in accordance with one of a plurality of operational modes (e.g., Bluetooth, 802.11a, 802.11b, et cetera). The receiver front-end 66 generates an IF signal 26 based on the selection signal 34. As previously mentioned, the selection signal 34 is indicative

of the particular mode of operation for the multimode receiver 62.

As shown, the IF signal 26 includes an in-phase component (I) and a quadrature component (Q). The particular frequency for the IF signal 26 is dependent on the particular mode of operation. For example, if the mode of operation is Bluetooth, the intermediate frequency signal 26 may have an intermediate frequency of 2 MHz. If, however, the mode of operation is 802.11b, the intermediate frequency signal 26 may have an intermediate frequency at base-band.

The 1<sup>st</sup> receiver multiplexor 68, based on the selection signal 34, provides the I and Q components of the IF signal 26 to either the receiver low pass filter 70 or the receiver band-pass filter 72. When the mode of operation is 802.11b, the selection signal 34 instructs the 1<sup>st</sup> receiver multiplexor 68 to provide the I and Q components of IF signal 26 to the receiver low pass filter 70. Conversely, if the mode of operation is Bluetooth, the 1<sup>st</sup> receiver multiplexor 68 provides the I and Q components of the IF signal 26 to the receiver band-pass filter 72.

The low pass filter 70 filters the I component and Q component of IF signal 26 to produce a low pass filtered I signal 78 and a low pass filtered Q signal 80. These signals are then provided to the 2<sup>nd</sup> receiver multiplexor 74. The receiver band-pass filter 72 filters the I and Q components of the IF signal 26 to produce band-pass filtered Q signal 82 and band-pass filtered I signal 84. These signals are also provided to the 2<sup>nd</sup> receiver

multiplexor 74. As one of the average skill in the art will appreciate, the frequency response of the low pass filter 70 and the band pass filter 72 will be in accordance with known filtering operations to adequately pass the frequencies of interest and attenuate other frequencies.

Based on the selection signal 34, the 2<sup>nd</sup> receiver multiplexor 74 outputs either the low pass filtered I and Q signals 78 and 80 or the band-pass filtered I and Q signals 82 and 84 to the receiver amplifier module 76. The receiver amplifying module 76 amplifies the I and Q components to produce amplified I and Q components 86. As one of average skill in the art will appreciate, if the multimode receiver 62 is designed to support both Bluetooth operations and 802.11b operations, the amplifying circuitry within the receiver amplifying module 76 in combination with the amplifier within the receiver front-end 66 will be designed to meet the more stringent requirements of the 802.11b specification. By designing these components for the more stringent 802.11b requirements, the requirements for Bluetooth will be inherently met. The multimode receiver 62 will be described in greater detail with reference to Figure 6.

The multimode transmitter 60 is operably coupled to receive an I and Q component of an input signal 100. The I and Q components of the input signal are representative of a modulated signal at an IF frequency based on the particular mode of operation. For example, if the mode of operation is Bluetooth, the frequency of the I and Q components of the input signal will be approximately 0 MHz.

Alternatively, if the mode of operation is 802.11b, the input signal 100 will have a frequency at base-band.

The transmitter amplifying module 88 receives the I and Q components of input signal 100 and amplifies them. The transmitter amplifying module 88 provides the amplified input signal 100 to the 1<sup>st</sup> transmitter multiplexor 90. Based on the selection signal 34, the 1<sup>st</sup> transmitter multiplexor 90 outputs the I and Q components to either the transmitter low pass filter 92 (e.g., for Bluetooth operation) or the transmitter low pass filter 94 (e.g., for 802.11b operation). If the selection signal 34 indicates that the low pass filter 92 is to receive the signals, the low pass filter 92 filters the I and Q components to produce low pass filtered Q signal 102 and low pass filtered I signal 104. Alternatively, if the selection signal 34 indicates that low pass filter 94 filters is to receive the signals, the filter 94 filters the signal to produce low pass filtered Q signal 106 and low pass filtered I signal 108. As one of average skill in the art will appreciate, the frequency response of filters 92 and 94 will be based on the particular mode of operation. For example, filter 92 will have a frequency response to pass baseband signals, while filter will have a frequency response to pass 2 MHz signals.

The 2<sup>nd</sup> transmitter multiplexor 96 outputs either the low pass filtered I and Q signals 102 and 104 or the low pass filtered I and Q signals 106 and 108 based on the selection signal 34. The 2<sup>nd</sup> transmitter multiplexor 96 provides the selected IF signal 100 to the transmitter front-end 98. Based on the selection signal 34, the

transmitter front-end 98 up-converts the frequency of the IF signal 110 and amplifies it to produce the outbound RF signal 52. The multimode transmitter 64 will be described in greater detail with reference to Figure 7.

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Figure 3 illustrates a schematic block diagram of another integrated multimode radio 120 that includes a multimode receiver 122 and a multimode transmitter 124. The multimode receiver 122 includes a receiver front-end 124, a receiver multiplexor 130, a 1<sup>st</sup> receiver IF section 126, and a 2<sup>nd</sup> receiver IF section 128. The multimode transmitter 124 includes a 1<sup>st</sup> transmitter IF section 174, a 2<sup>nd</sup> transmitter IF section 176, a transmitter multiplexor 172, and a transmitter front-end 170.

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In operation, the receiver front-end 124 is operably coupled to receive the RF signal 24. As previously mentioned, the RF signal 24 is modulated in accordance with a particular wireless communication standard (e.g., Bluetooth, IEEE 802.11a, IEEE 802.11b, et cetera). The front-end receiver 124 includes a low noise amplifier 132 and a mixing module 134. The low noise amplifier 132 receives the RF signal 24 and a gain setting signal 146. The gain setting signal 146 sets the gain of the low noise amplifier 132 at a particular gain within a range of gain of the low noise amplifier. As such, the low noise amplifier 132 has a programmable gain, which is set in accordance with the gain setting signal 146. Based on the selected gain, the low noise amplifier 132 produces an amplified RF signal 144 from the RF signal 24.

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The mixing module 134, which will be described at greater detail with reference to Figure 4, receives the amplified RF signal 144 and an operational selection signal 148. The mixing module 134 produces an intermediate frequency signal from the amplified RF signal 144 based on the operational selection signal 148. The receiver multiplexor 130 receives the intermediate frequency signal from the front-end 124 and provides it as either intermediate frequency signal 150 to the 1<sup>st</sup> receiver IF section 126 or as another IF signal 152 to the 2<sup>nd</sup> receiver IF section 128. As one of average skill in the art will appreciate, the multimode receiver 122 may include additional receiver IF sections. Such additional IF sections would correspond to different modes of operation for the integrated multimode radio 120. For example, one mode may be in accordance with 802.11a, another mode in accordance with 802.11b, and another mode in accordance with Bluetooth.

The 1<sup>st</sup> receiver IF section 126 includes a 1<sup>st</sup> receiver filter module 136, and a 1<sup>st</sup> receiver amplifier module 138. The receiver filter module 136 is operably coupled to receive the IF signal 150 and filters it to produce a 1<sup>st</sup> filtered IF signal 158. The 1<sup>st</sup> receiver amplifying module 138 receives the 1<sup>st</sup> filtered IF signal 150 and a gain 156 that is set in accordance with the gain setting signal 146. Based on the gain 156, the 1<sup>st</sup> receiver amplifier module 138 amplifies the 1<sup>st</sup> receiver IF signal 158 to produce a 1<sup>st</sup> IF signal 150. The gain of the 1<sup>st</sup> receiver amplifying module is programmed over an IF gain range that is based on the IF gain setting signal 154. As one of average skill in the art will appreciate, the gain selected for the low noise

amplifier 132, the 1<sup>st</sup> receiver filter module 136, and the 1<sup>st</sup> receiver amplifier module 138 are chosen to meet the requirements of the particular mode of operation supported by this path and on the power level of the received RF signal 24. For example, if this path supports 802.11b, the gain for these modules is set to meet the noise requirements and hence performance requirements for 802.11b for a given power level of the received RF signal 24.

The 2<sup>nd</sup> receiver IF section 128 includes a 2<sup>nd</sup> receiver filter module 140 and a 2<sup>nd</sup> receiver amplifying module 142. The 2<sup>nd</sup> receiver filter module 140 is operably coupled to filter the IF signal 152 to produce the 2<sup>nd</sup> filtered IF signal 162. The 2<sup>nd</sup> receiver amplifying module 142, based on gain 156, amplifies the 2<sup>nd</sup> filtered IF signal 162 to produce the 2<sup>nd</sup> IF signal 164. In this illustration, the 1<sup>st</sup> receiver IF section 126 supports a more stringent performance requirement based wireless communication standard than the 2<sup>nd</sup> receiver IF section 128. As such, the gain setting signal 146 and gain 156 are set to meet the more stringent requirements for the 1<sup>st</sup> receiver IF section. As such, the gain of the 2<sup>nd</sup> receiver IF section 128 is set as if the 1<sup>st</sup> receiver IF section 126 were actively processing the IF signal 150.

The multimode transmitter 124 is operably coupled to receive a 1<sup>st</sup> input signal 190 or a 2<sup>nd</sup> input signal 192. The 1<sup>st</sup> input signal 190 is representative of a modulated signal in accordance with a particular mode of operation of the integrated multimode radio 120. The 2<sup>nd</sup> input signal 192 is a modulated signal in accordance with another operational mode of the integrated multimode radio 120.

For example, the 1<sup>st</sup> input signal 190 may be a modulated signal in accordance with 802.11b while the 2<sup>nd</sup> input signal 192 is a modulated signal in accordance with Bluetooth.

5           The 1<sup>st</sup> transmitter IF section 174 includes a 1<sup>st</sup> transmitter filter module 178 and a 1<sup>st</sup> transmitter amplifying module 180. The 1<sup>st</sup> transmitter filter module 178 filters the 1<sup>st</sup> input signal 190 to produce a 1<sup>st</sup> filtered IF signal 194. The 1<sup>st</sup> transmitter amplifier  
10 module 180 receives the 1<sup>st</sup> filtered IF signal 194 and the gain 156. The 1<sup>st</sup> transmitter amplifying module 180 amplifies the 1<sup>st</sup> filtered signal 194 based on gain 156 to produce the 1<sup>st</sup> IF signal 190.

15           Similarly, the 2<sup>nd</sup> transmitter IF section 176 includes a 2<sup>nd</sup> transmitter filter module 182 and a 2<sup>nd</sup> transmitter amplifying module 184. The 2<sup>nd</sup> transmitter filter module 182 filters the 2<sup>nd</sup> input signal 192 to produce the 2<sup>nd</sup> filtered IF signal 196. The 2<sup>nd</sup> transmitting amplifying  
20 module 184 amplifies the 2<sup>nd</sup> filtered IF signal 196 in accordance with gain 156 to produce the 2<sup>nd</sup> IF signal 200.

As one of average skill in the art will appreciate, when the 1<sup>st</sup> transmitter IF section 174 is processing a  
25 modulated signal of a wireless communication standard that has more stringent performance requirements than the signals processed by the 2<sup>nd</sup> transmitter IF section 176, the gain setting signal 146 and gain 156 will be selected based on the performance requirements of the 1<sup>st</sup> path. By setting  
30 the gain to meet the performance requirements of the more stringent path, the less stringent requirements of the other path or paths will be met. As one of average skill



in the art will also appreciate, the multimode transmitter 124 may include more transmitter IF sections than the two shown. For example, the transmitter 124 may include three sections: one for processing Bluetooth signals, one for  
 5 processing 802.11a signals, and one for processing 802.11b signals.

The transmitter multiplexor 172 receives the 1<sup>st</sup> IF signal 198 and/or the 2<sup>nd</sup> IF signal 200. Based on the  
 10 operational selection signal 148, the transmitter multiplexor 172 outputs either the 1<sup>st</sup> IF signal 198 or the 2<sup>nd</sup> IF signal 200 to the transmitter front-end 170.

The transmitter front-end 170 includes a mixing module  
 15 186 and a power amplifier 188. The mixing module 186 receives the IF signal 198 or 200 and, based on the operational selection signals 148, up-converts the frequency to produce a representative RF signal 202. The power amplifier 188 based on a gain setting signal 146  
 20 amplifies the representative RF signal 202 to produce an outbound RF signal 52. Note that the gain setting signal 146, gain 156, and IF gain setting signal 154 are selected to meet the more stringent requirements of the 1<sup>st</sup> transmitter RF section 174. As such, by setting the gains  
 25 to meet the more stringent requirements of a particular wireless communication protocol, the less stringent performance requirements of other wireless communication protocols will be met.

30 Figure 4 illustrates a more detailed schematic block diagram of the multimode receiver 12 of the integrated multimode radio 10 of Figure 1. The multimode receiver 12

includes the receiver front-end 16, the 1<sup>st</sup> IF stage 20, the multiplexor 18, the 2<sup>nd</sup> IF stage 22, a power detection logic circuit 258 and may further include a 3<sup>rd</sup> IF stage 246. The receiver front-end 16 includes a low noise amplifier 132  
 5 and mixing module 134. The mixing module 134 includes an I mixer 214 and a Q mixer 216.

The low noise amplifier 132 is operably coupled to amplify the RF signal 24 to produce an amplified RF signal  
 10 144. The I mixer 214 is operably coupled to mix (i.e., multiply) an I component of the amplified RF signal 144 with an I oscillation 220. The I oscillation 220 is representative of an I component of a local oscillation. The frequency of the local oscillation will be dependent  
 15 upon the desired intermediate frequency. For example, if the frequency of the RF signal 24 is 2.402 GHz and the desired intermediate frequency is 2 MHz, the frequency of the local oscillation will be 2.400 GHz. Alternatively, if the RF signal 24 has a frequency of 2.400 GHz and the  
 20 desired IF is 0, or base-band, the local oscillation will have a frequency of 2.400 GHz.

The Q mixer 216 mixes (e.g., multiples) a Q component of the amplified RF signal 144 and a Q oscillation 222 of a  
 25 local oscillator. The outputs of Q mixer 216 and I mixer 214 are provided to the multiplexor 18. Note that, in general, the local oscillation selected for the I and Q oscillations 220 and 222 are based on the selection signal 34, which is indicative at the particular mode of  
 30 operation.

The multiplexor 18 outputs the IF signal 26 to one of the IF stages 20, 22 or 246. If the multimode receiver 12 is supporting only two modes of operation, the 3<sup>rd</sup> IF stage 246 may be omitted. For example, the multimode receiver 12 may support only Bluetooth and 802.11b. Alternatively, if the multimode receiver 12 supports three different modes, for example 802.11a, 802.11b and Bluetooth, the 3<sup>rd</sup> IF stage 246 will be included.

The 1<sup>st</sup> IF stage 20 includes the 1<sup>st</sup> filter module 136, the 1<sup>st</sup> amplifying module 138, a DC feedback circuit 228, an analog to digital converter 230, and a demodulator 232. The 1<sup>st</sup> filtering module 136 and 1<sup>st</sup> amplifying module 138 perform as previously discussed with reference to Figure 3. The DC feedback circuit 228 is operably coupled to remove a DC component from the output of the 1<sup>st</sup> amplifying module 138. The DC offset may result from the local oscillation coupling into the receiver section, which is then self mixed. As mentioned with reference to Figure 3, the gains set within the low noise amplifier 132, the 1<sup>st</sup> filtering module 136 and the 1<sup>st</sup> amplifying module 138 are determined based on meeting the performance requirements of the more stringent wireless communication specification.

To determine the particular gains to be used, the power detection logic 258 determines the power level of the IF signal 24 to produce a gain adjustment signal 260. Accordingly, the gains of the low noise amplifier 132, the 1<sup>st</sup> filtering module 136 and the 1<sup>st</sup> amplifying module 138 are set in accordance with the gain adjustment signal 260. As one of average skill in the art will appreciate, the power level of the RF signal may be determined by

monitoring the output of the 1<sup>st</sup> amplifier module 138 to determine the magnitude of the signals. Based on the magnitude of the signal and the known operating parameters of the 1<sup>st</sup> IF stage 20, the power level of the RF signal may be readily determined.

The analog to digital converter 230 receives the 1<sup>st</sup> IF signal 160 (i.e., the output of the 1<sup>st</sup> amplifying module 138) and converts it into a digital signal. The demodulator 232 receives the digital signal and demodulates it to produce recaptured data 234. The demodulator 232 utilizes a demodulation scheme in accordance with the particular function supported by the 1<sup>st</sup> IF stage 20. For example, if the 1<sup>st</sup> IF stage 20 corresponds to 802.11b, the demodulator 232 performs an 8-bit CCK demodulation.

The 2<sup>nd</sup> IF stage 22 includes the 2<sup>nd</sup> filter module 140, the 2<sup>nd</sup> amplifying module 142, a DC feedback circuit 238, an analog to digital converter 240 and a demodulator 242. The functionality of the 2<sup>nd</sup> filtering module 140 and 2<sup>nd</sup> amplifying module 142 are as previously discussed in Figure 3. The DC feedback circuit 238 performs a similar function as DC feedback circuit 238 to remove DC offset that may be present in the IF signal.

The analog to digital converter 240 receives the 2<sup>nd</sup> IF signal 164 (i.e., the output of the 2<sup>nd</sup> amplifying module 142) and converts it into a digital signal. The demodulator 242 demodulates the digital signal to recapture data 234. The particular demodulation scheme is dependent on the wireless communication standard supported by the 2<sup>nd</sup> IF stage 22.

The 3<sup>rd</sup> IF stage 246 includes a 3<sup>rd</sup> filtering module 248, a 3<sup>rd</sup> amplifying module 250, a DC feedback circuit 252, an analog to digital converter 254, and a demodulator 258.

5 The functionality of the 3<sup>rd</sup> IF stage 246 is comparable to the functionality of the 1<sup>st</sup> and 2<sup>nd</sup> IF stages. The 3<sup>rd</sup> amplifying module 250 produces a 3<sup>rd</sup> IF signal that is converted to a digital signal by the analog to digital converter 254. The demodulator 256 demodulates the digital  
10 signal to recapture data 234 based on the demodulation scheme of the wireless communication specification supported by the 3<sup>rd</sup> IF stage 246.

Figure 5 illustrates a more detailed schematic block  
15 diagram of multimode transmitter 14. In this illustration, the multimode transmitter 14 includes the transmitter front-end 42, multiplexor 40, the 1<sup>st</sup> IF stage 36, the 2<sup>nd</sup> IF stage 38 and may further include a 3<sup>rd</sup> IF stage 304. The three IF stages 36, 38 and 304 are operably coupled to  
20 receive data 294. Depending on the particular mode of operation of the multimode transmitter, one of the IF stages will be activated. For example, in a two mode transmitter, the 1<sup>st</sup> IF stage 36 may correspond to 802.11b, the 2<sup>nd</sup> IF stage 38 may correspond to Bluetooth. If the  
25 multimode transmitter 14 is further to process 802.11a data, the 3<sup>rd</sup> IF stage may be in accordance with 802.11a. In each of the IF stages, the data 294 is modulated via modulator 292, 302 or 312. The particular type of modulation performed is dependent upon the particular  
30 operational mode supported by the particular IF stage. For example, if the 1<sup>st</sup> IF stage 36 is supporting 802.11b, the modulation scheme used by modulator 292 may be 8-bit CCK.

The modulated signal in each of the IF stages 36, 38 and 304, is converted to an analog signal by the digital to analog converter 290, 300 or 310. The corresponding analog signal is then filtered by the 1<sup>st</sup> filtering module 178, the 2<sup>nd</sup> filtering module 182 or the 3<sup>rd</sup> filtering module 308. The filtered signal is then amplified either by the 1<sup>st</sup> amplifying module 180, the 2<sup>nd</sup> amplifying module 184 or the 3<sup>rd</sup> amplifying module 306. The functionality of the 1<sup>st</sup> and 2<sup>nd</sup> amplifying modules and filtering modules are as previously discussed with reference to Figure 3. The 3<sup>rd</sup> amplifying module 306 and the 3<sup>rd</sup> filtering module 308 will perform in a similar fashion as the amplifying and filtering modules of the 1<sup>st</sup> and 2<sup>nd</sup> IF stages 36 and 38 but in accordance with the particular mode of operation that it supports.

The multiplexor 40 provides the IF signal from the 1<sup>st</sup>, 2<sup>nd</sup> or 3<sup>rd</sup> IF stages 36, 38 or 304 to the transmitter front-end 42 based on the selection signal 34. The transmitter front-end 42 includes the power amplifier 188 and the mixing module 186. The mixing module 186 includes an I mixer 274, a Q mixer 276, and a summation module 278. The I mixer 274 mixes an I component 280 of the selected IF signal with an I component of a local oscillator. The Q mixer 276 mixes a Q component of the selected IF signal with a Q component 282 of the local oscillator. The outputs of the I and Q mixers 274 and 276 are summed together via summation module 278. The resulting up-converted RF signal 284 is amplified via power amplifier 188 to produce the outbound RF signal 52.

Figure 6 illustrates a more detailed schematic block diagram of the multimode receiver 62 of the integrated multimode radio 60 of Figure 2. The multimode receiver 62 includes the receiver front-end 66, the 1<sup>st</sup> multiplexor 68, the receiver low pass filter 70, the receiver band-pass filter 72, the 2<sup>nd</sup> multiplexor 74, the receiver amplifying module 76, an analog to digital converter 334 and a demodulator 338. The receiver front-end 66 includes a low noise amplifier 320 and a mixing module 322. The mixing module 322 includes an I mixer 324 and a Q mixer 326.

The low noise amplifier 320 amplifies the RF signal 24 to produce an amplified RF signal 332. The I mixer 324 mixes an I component of the amplified RF signal 332 with an I component 328 of a local oscillator. The resulting I component of the mixed signal is provided to the 1<sup>st</sup> multiplexor 68. The Q mixer 326 mixes a Q component 330 of the local oscillation with a Q component of the amplified RF signal 332. The resulting mixed Q component is provided to the 1<sup>st</sup> multiplexor 68.

Based on the selection signal 34, the 1<sup>st</sup> multiplexor 68 outputs the I and Q components to either the received low pass filter 70 or the received band-pass filter 72. For example, if the mode of operation is in accordance with 802.11b, the 1<sup>st</sup> multiplexor 68 would provide the I and Q components to the low pass filter 70. If, however, the mode of operation is Bluetooth, the 1<sup>st</sup> multiplexor 68 would provide the I and Q components to the band-pass filter 72.

The 2<sup>nd</sup> multiplexor 74 outputs either the low pass filtered I and Q signals 78 and 80 or the band-pass

filtered I and Q signals 82 and 84 to the receiver  
 amplifying module 76 based on the mode of operation. As  
 one of average skill in the art will appreciate, the gain  
 set within the amplifying module 76 and the gain of the low  
 5 noise amplifier 320 are set in accordance with the more  
 stringent performance requirements of the multiple wireless  
 communication protocol supported by the multimode receiver  
 62 and the power level of the RF signal. For example, if  
 multimode receiver 62 is supporting 802.11b and Bluetooth,  
 10 the more stringent performance requirements are in  
 accordance with 802.11b. As such, the gain set within the  
 low noise amplifier 320 and within the receiving amplifying  
 module 76 will be in accordance with the performance  
 requirements of 802.11b. The determination of the gains  
 15 for these devices will be in accordance with the gain  
 adjustment signals 260 previously described with reference  
 to Figure 4.

The I and Q components 86 outputted by the receiver  
 20 amplifying module 76 are converted to digital signals via  
 analog to digital converter 334. The digital I and Q  
 signals are demodulated by demodulator 338 to produce  
 recaptured data 234. As one of average skill in the art  
 will appreciate, the demodulator 338 demodulates the data  
 25 in accordance with the particular mode of operation.

Figure 7 illustrates a more detailed schematic block  
 diagram of multimode transmitter 64 that was illustrated in  
 the integrated multimode radio 60 of Figure 2. The  
 30 multimode transmitter 64 includes the front-end 98,  
 multiplexor 96, low pass filter 90, band-pass filter 92,



multiplexor 90, amplifying module 88, two digital to analog converters 342 and 344 and a modulator 340.

Depending on the particular mode of operation, the modulator 340 modulates data 346 to produce a digital I signal and a digital Q signal. For example, if the mode of operation is Bluetooth, the modulator 340 modulates the data in accordance with FSK. The digital to analog converters 342 and 344 convert the digital I and Q signals into the I and Q components of input signal 100. The performance of amplifying module 88, multiplexor 90, band-pass filter 92, low pass filter 90 and multiplexor 96 are as previously discussed with reference to Figure 2.

The front-end 98 includes a power amplifier 272 and mixing module 270. The mixing module includes an I mixer 274, a Q mixer 276 and a summation module 278. The I mixer 274 mixes an I component of the selected IF signal with an I component 280 of the local oscillator. The Q mixer 276 mixes a Q component of the selected IF signal with a Q component 282 of the local oscillation. The resulting mixed signals are summed together by summation module 278 to produce an up-converted signal that is a representative RF signal 284. The power amplifier 272 amplifies the representative RF signal 284 to produce an outbound RF signal 52. Note that the I and Q components of the local oscillators 280 and 282 are based on the particular mode of operation.

Figure 8 illustrates a schematic block diagram of an integrated multimode radio 350. The radio 350 includes the multimode receiver 12, the multimode transmitter 14 and a

local oscillator 352. The multimode receiver 12 includes the shared front-end 16, a 1<sup>st</sup> IF stage 20, and the 2<sup>nd</sup> IF stage 22. The multimode transmitter 14 includes the 1<sup>st</sup> transmitter IF stage 36, the 2<sup>nd</sup> transmitter IF stage 38, multiplexor 40 and the shared transmitter front-end 42. The local oscillator section 352 produces the I and Q components 220 and 222 that are used within the shared front-end 16 of multimode receiver 12 and the I and Q components 280 and 282 that are used within the shared front-end within the multimode transmitter 14. As one of average skill in the art will appreciate, the local oscillation used for the receiver may be the same or a different local oscillation than is used for the transmitter.

The implementation of the integrated multimode radio 350 includes low pass filters (LPF), programmable gain amplifiers (PGA), DC offset cancellation circuitry in the receive paths, fixed and/or variable gain buffers in the transmitter path and multiplexor circuits within the receive and transmit paths. The variable low noise amplifiers (LNA) and down converter mixers in the receive path are shared for both IF stages. The up-converter mixers in the transmit path and the variable power amplifier are shared for both IF stages 36 and 38.

In operation, the receiver path receives a radio frequency signal via an external antenna and is amplified by a high performance low noise amplifier. The amplified signal is then down-converted by the receiver mixer either to an intermediate frequency (IF) for Bluetooth operation or directly to base-band (zero IF) for 802.11b operation.

For Bluetooth operations, the IF signal is filtered via the band-pass filters (BPF) to reject noise and interference and then through a differentiator that extracts the frequency signal. The peak detector and slicer finish the frequency demodulation signal extraction.

For 802.11b applications, the base-band signal from the down-converter mixer is passed through the low pass filters (LPF) to reject noise and interference out of the signal band. The filtered signals are then amplified by programmable gain amplifiers (PGA) before being buffered through the base-band digitization and processing circuits, which are either integrated on the same chip or off chip on another base-band chip. The DC cancellation circuits (e.g., amplifiers and resistors) are used to cancel DC offset that results from direct conversion to base-band.

In the transmitter path for Bluetooth operation, the modulated signal from the digital demodulator goes through low pass filters to band limit the signal to a useful signal bandwidth. The signal is then buffered by a fixed or variable gain buffer prior to reaching the multiplexor. The signal is then up-converted by the transmit mixer to a desired radio frequency, which is then amplified by the power amplifier.

The preceding discussion has presented various embodiments for integrated multimode radios. By sharing similar functioning blocks for various modes of operation, and designing such shared blocks to meet the more stringent designed requirements, an integrated multimode receiver and/or integrated multimode transmitter is obtained. As one

of average skill in the art will appreciate, other embodiments may be derived from the teachings of the present invention, without deviating from the scope of the claims.